DEPARTMENT OF

CIVIL ENGINEERING

REPORT ON
ANNUAL TESTING OF CONCRETE SPECIMENS (PHASES I TO X) AT TREAT ISLAND, MAINE

for

CANMET
ENERGY, MINES AND RESOURCES CANADA

J. E. McInerney, MScE.
Research Engineer
University of New Brunswick

T.W. Bremner, PhD., P.Eng.
Professor of Civil Engineering
University of New Brunswick

UNIVERSITY OF NEW BRUNSWICK

FREDERICTON NEW BRUNSWICK CANADA

AUGUST 1989

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J.M. McInerney, MScE.
Research Engineer
University of New Brunswick

and

T.W. Bremner, PhD., P.Eng.,
Professor of Civil Engineering
University of New Brunswick

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MICROMEDIA

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1. INTRODUCTION

For 1989 The Department of Supply and Services awarded a contract to the University of New Brunswick covering the cleaning and testing of all concrete test blocks incorporating fly ash/slag/silica fume that are located at Treat Island, and the calculation of the number cycles of freezing and thawing of concrete specimens for the winter of 1988/89 based on temperature logger data. A copy of the contract is given in Appendix A.

2. IDENTIFICATION AND PREPARATION OF TEST SPECIMENS

The concrete test specimens at Treat Island are listed in Table I and a diagram of specimen location is presented in Figure I. The prisms were first cleaned of seaweed and silt with metal scrapers and wire brushes. They were then identified by the markings on the stainless steel straps which had been previously placed around them.

3. PULSE VELOCITY MEASUREMENTS

The nondestructive examination of concrete prisms utilized a battery powered "Pundit" manufactured by C.N.S. Electronics Ltd. (London, England) Serial No. 84111848. The meter was calibrated to a reference bar at 26.0 microseconds, at the beginning and periodically throughout the testing. Transducers of fifty millimeter diameter were used with a coupling medium made from kaolinite and glycerol. Readings were taken at the center of each specimen and are recorded in Table II.

4. RESONANT FREQUENCY

Transverse resonant frequency measurements were performed using procedures and with equipment meeting the requirements of ASTM Designation C215-60. The results are recorded in Table III.

Prior to and after visiting the site, the operation of the equipment was verified using a 1' x 1' x 3' prism and a 3" x 4" x 16" prism of concrete stored in the laboratory air. No change in reading was noted. Also the frequency readings of the oscillator was checked with the Department of Electrical Engineering standard and found to be in agreement with it. The mass of the driving unit had no noticeable effect on the frequency readings.

5. PHOTOGRAPHIC AND COLOUR SLIDE RECORD

Photographs of all of the individual specimens were hand delivered to Mr. George Carette of CANMET on August 1, 1989. A set of slides has been stored in room B19, Head Hall, University of New Brunswick, Fredericton, for future reference. All slides and photographs were taken with a +1 setting on a Minolta XD11 camera.

6. VISUAL EXAMINATION

Using the rating system shown in Figure II the specimens were examined and the ratings and remarks recorded in Table IV. The evaluation was done independently by four people and in the few instances where differences of opinion

existed, a consensus was arrived at. A visual rating of three or greater was assumed to signify significant deterioration.

7. NATURE AND DEGREE OF DETERIORATION

Yearly inspections reveal that surface deterioration of concrete specimens at Treat Island is increasing with increasing water to cement (w/c) ratio and with increasing cement replacement with supplementary cementing materials.

PHASE IA.

After 11 years of exposure significant surface deterioration (rating 3 or greater) has occurred with w/binder=0.5 and 65% slag. Also significant surface deterioration has occurred with w/binder=0.6 and with 45% and 65% slag replacement. Specimens were stood on end and the bottom surface examined. Slightly less deterioration has occurred on the bottom than on the sides, end or top with the exception of specimen A01 which had significant deterioration on the bottom edge (Plate I).

PHASE IB

All specimens without air entrainment and with a superplasticizer have completely deteriorated (specimens SP3 and SP6). Only 50% of the volume of the specimen containing neither air entrainment nor superplasticizers remains (rating of 8 for specimen SP4) after 11 years. In comparison a rating of 8 was given to the specimen containing Brand "A"

superplasticizer after 8 years, and the Brand "B" superplasticizer had a rating of 8 after only 4 years. Evidence of a surface layer more durable than the underlying layer of material can be seen in Plates IIA and IIB. Loss of bond at the cement paste-aggregate interface can be clearly seen in Plate IIB.

PHASE II

After 10 years of exposure no significant deterioration has taken place in specimens with 25% replacement of cement with fly ash. Significant surface deterioration has occurred with all combinations of fly ash and slag. Specimens were stood on end and the bottoms examined for series D, E and F. Generally surface deterioration on the bottom was less than the top with the exception of D13 (see Plate III).

PHASE III

Significant deterioration has occurred with all semi-lightweight concretes with cement contents of 240 kg/m^3. With cement contents of 343 and 459 kg/m^3 ratings are all less than 3 indicating only minor deterioration at all levels of cement replacement and with all types of cements.

In Series G (240 kg/m^3) significant to severe deterioration has occurred to the shoreward end of the specimens (see Plate IV-XII). The reduced drying on this the north facing end of the specimens has apparently led to a higher degree of saturation which in turn leads to greater

deterioration due to freezing and thawing. Significantly more popouts have occurred and appear to be almost as prevalent in the high binder content specimens as in the low binder content.

PHASE IV

Significant surface deterioration has occurred with a w/c ratio of 0.6 and 25% replacement of the cement with Lingan fly ash. The extent of deterioration after 3 years of exposure for the Lingan fly ash used for Series J, K, and L is about the same as the deterioration after 10 years for the fly ash from the Detroit Edison plant (series D, E, and F).

PHASE VA

After seven years exposure the specimens containing 80% granulated blast furnace slag show generally good performance with only the specimens with a water to binder ratio of 0.6 having a rating of 3. These specimens appear to be performing somewhat better than those in Phase II.

PHASE VB

Significant loss of concrete has occurred in all prisms made without air entrainment admixture. The damage to R01, R03 and R04 is most evident on the shoreward ends of the specimens that can not be seen in the photographs. The damage observed is similar to that experienced by specimen R02 where loss of concrete is at least 40 mm. All other specimens in the R series have a loss of about 20 mm of

concrete.

It would appear that the use of more than 10% silica fume as a replacement or as an addition results in significant surface deterioration.

PHASE VI-X

All prisms made in 1985 and in subsequent years do not show significant deterioration at this time.

It should be noted however that specimens in Phase VIII containing 55% fly ash replacement for cement and having a water to binder ratio of 0.35 (series V) are showing some surface deterioration after only 2 years exposure. Specimens Z01 to Z08 contain steel reinforcing and after two years no signs of steel corrosion can be seen.

8. A FREEZE-THAW RECORD FOR CONCRETE WINTER 1988/89

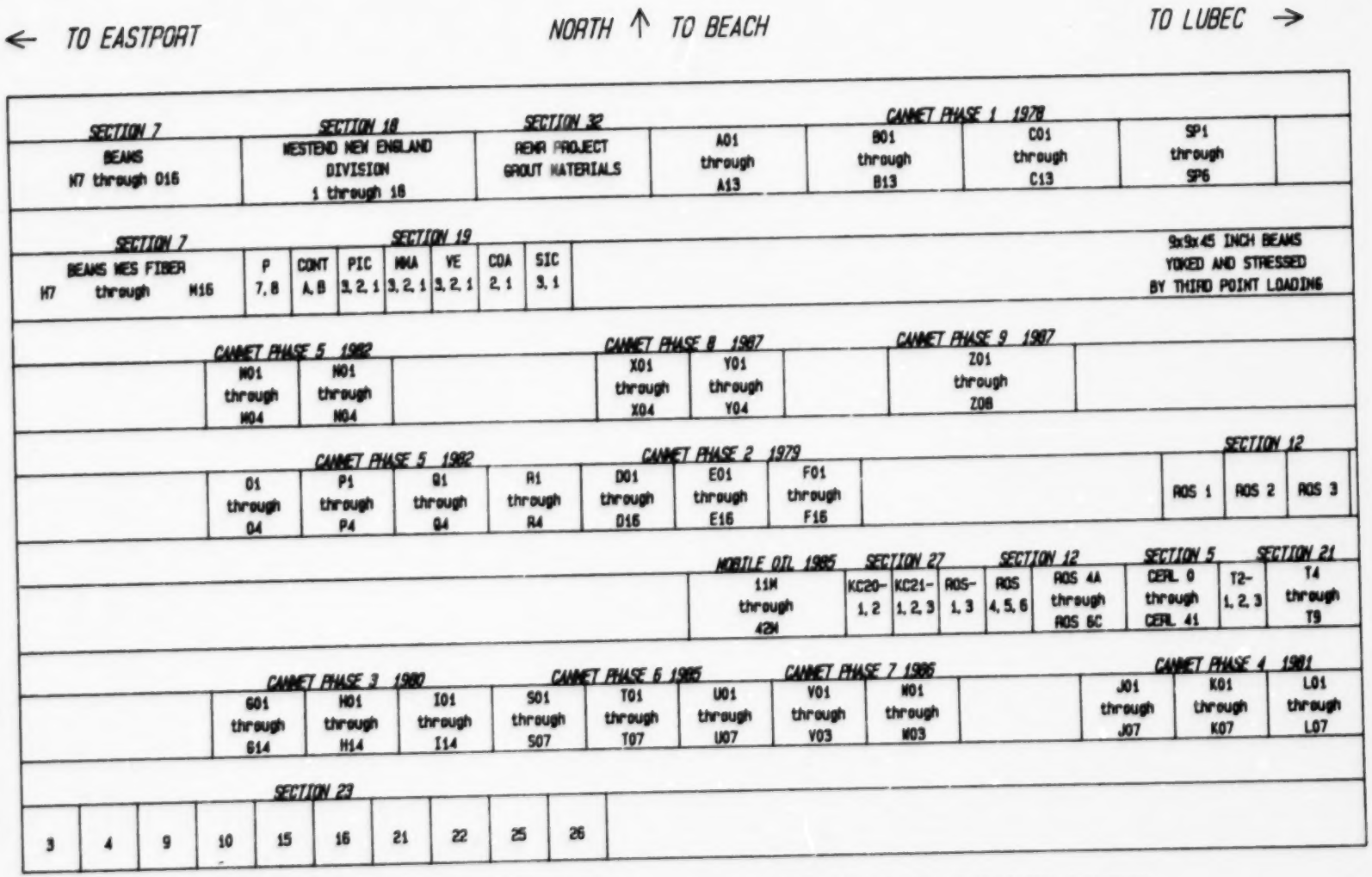
An XL-800 data logger manufactured by Richard Brancker Research Ltd. was used to record temperatures at Treat Island over the period from November 4, 1988 to May 17, 1989. Temperature sensors are located in concrete at the center of a 152 x 152 x 510 mm prism and at 25, 75 and 152 mm cover in a 305 x 305 x 915 mm prism. The prisms are located at mid-tide level and experience repeated cycles of freezing and thawing during the winter months. Temperature sensors are also located in the air above the high tide level and in the air/water at mid-tide level.

The number of freeze-thaw cycles experienced at each of the sensors is recorded in Table V and the

temperature record in graphical form is given Appendix B.

9. CONCLUSION

The CANMET testing program at Treat Island has revealed the importance of using a low water to cement ratio for concrete in a marine environment particularly when supplementary cementing materials are being used. In all instances non-air entrained concrete has proven to be not durable and complete disintegration occurs at or before 8 years of exposure. At this stage no difference in behaviour can be noted between the concrete specimens made with various types of cement or aggregates types.



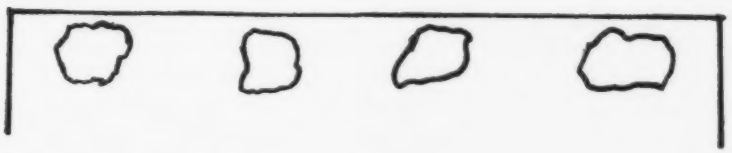
ARRANGEMENT OF TEST SPECIMENS ON RACK AT SEVERE WEATHERING EXPOSURE STATION, TREAT ISLAND, MAINE, AUGUST 1988

Figure 1

FIGURE II

VISUAL INSPECTION RATING SYSTEM

Rating of 0: Less than 15 aggregates are exposed



Rating of 1: More than 15 aggregates are exposed

Rating of 2: One half the aggregates immediately below the surface are exposed

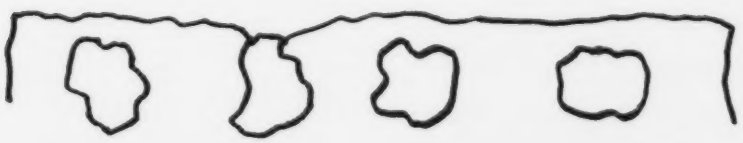
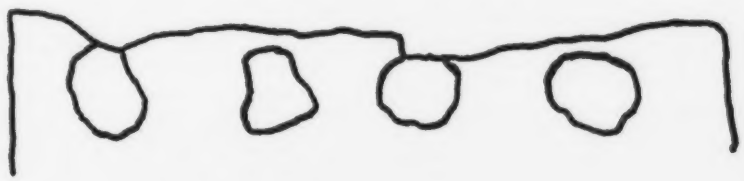


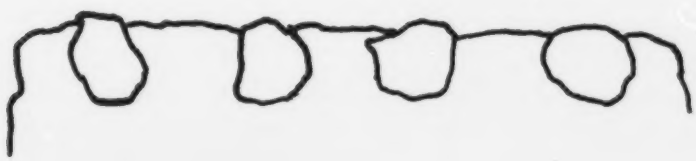
FIGURE II - (cont'd)

VISUAL INSPECTION RATING SYSTEM

Rating of 2: 80% of the surface aggregates are exposed



Rating of 4: Surface aggregates are exposed over 20% of their perimeter



Rating of 5: 90% of the surface aggregates are completely exposed to one half the perimeter of the coarse aggregate on the surface

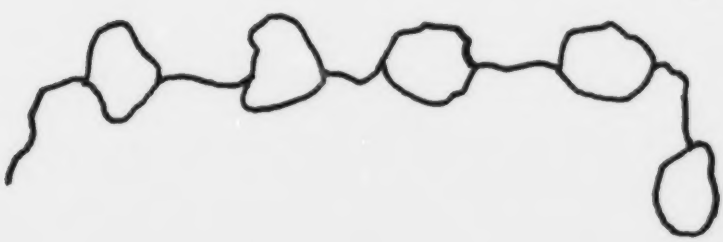


FIGURE II - (cont'd)

VISUAL INSPECTION RATING SYSTEM

Rating of 6: 95% volume of specimen remaining or loss of five or more surface aggregates in a local area.

Rating of 7: 80% of volume of specimen remaining or loss of concrete in a local area of depth equal to twice the nominal aggregate size.

Rating of 8: 50% of volume of specimen remaining

Rating of 9: 20% of volume of specimen remaining

Rating of 10: Specimen Gone

DSS File No.: 55SS.23440-8-9244.

APPENDIX "A"

Statement of Work

Title: Monitoring of Concrete Test Specimens at Treat Island--Year 1989

The Contractor and his staff shall travel to Treat Island and clean, test and inspect all of the fly ash/slag/silica fume concrete specimens that have been installed at Treat Island. Also, data shall be retrieved from the temperature logger and converted into Lotus 123 files and the number of freezing and thawing cycles determined for all five sensors.

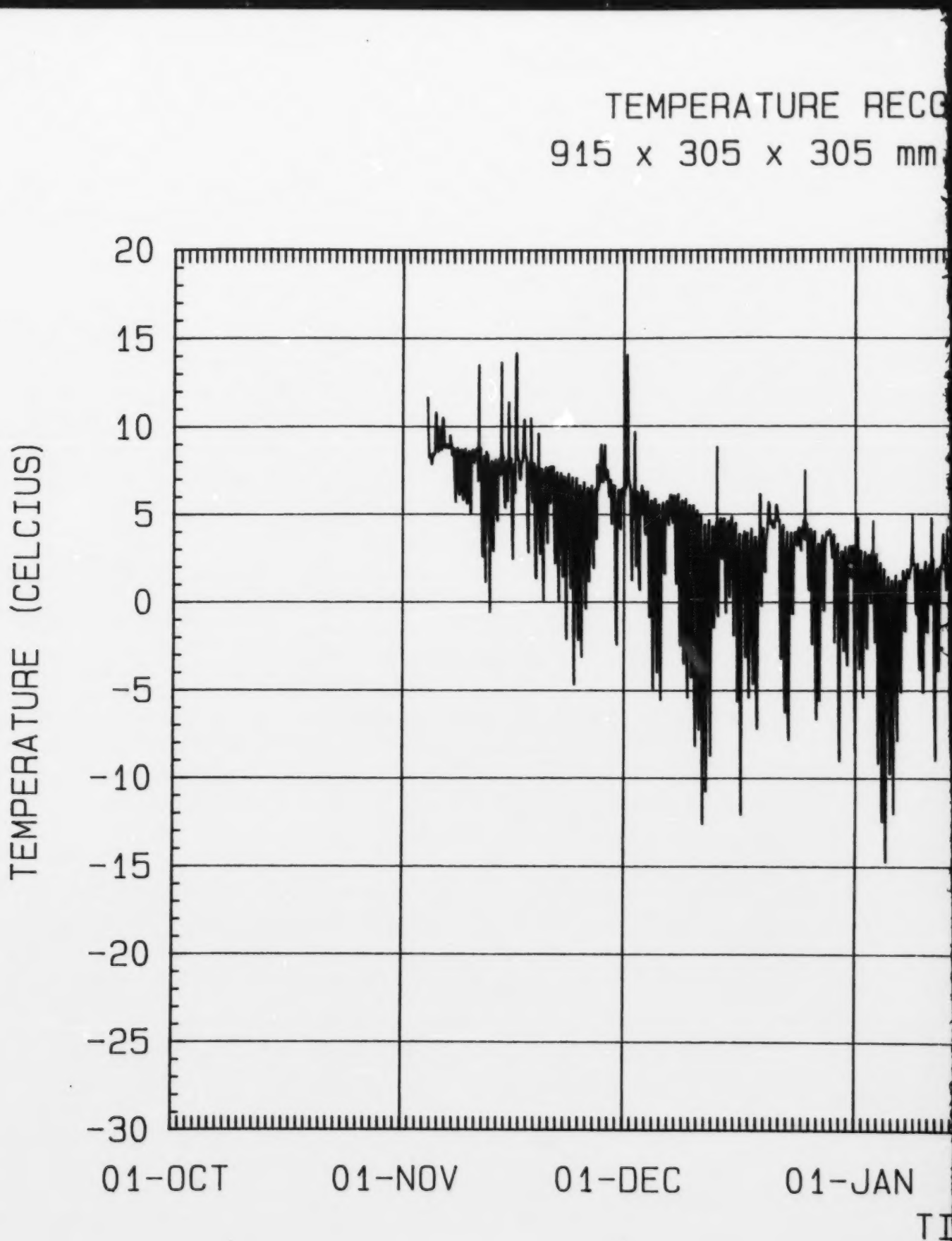
The Contractor shall carry out the following:

(a) clean and label each concrete prism
(b) visually inspect and rate each concrete prism
(c) provide one colour print/slide of each specimen
(d) retag specimens where necessary
(e) determine pulse velocity of each prism
(f) provide resonant frequency for each prism
(g) provide 10 copies of the report on testing and inspection as well as temperature records indicating number of freeze-thaw cycles experienced by the concrete.

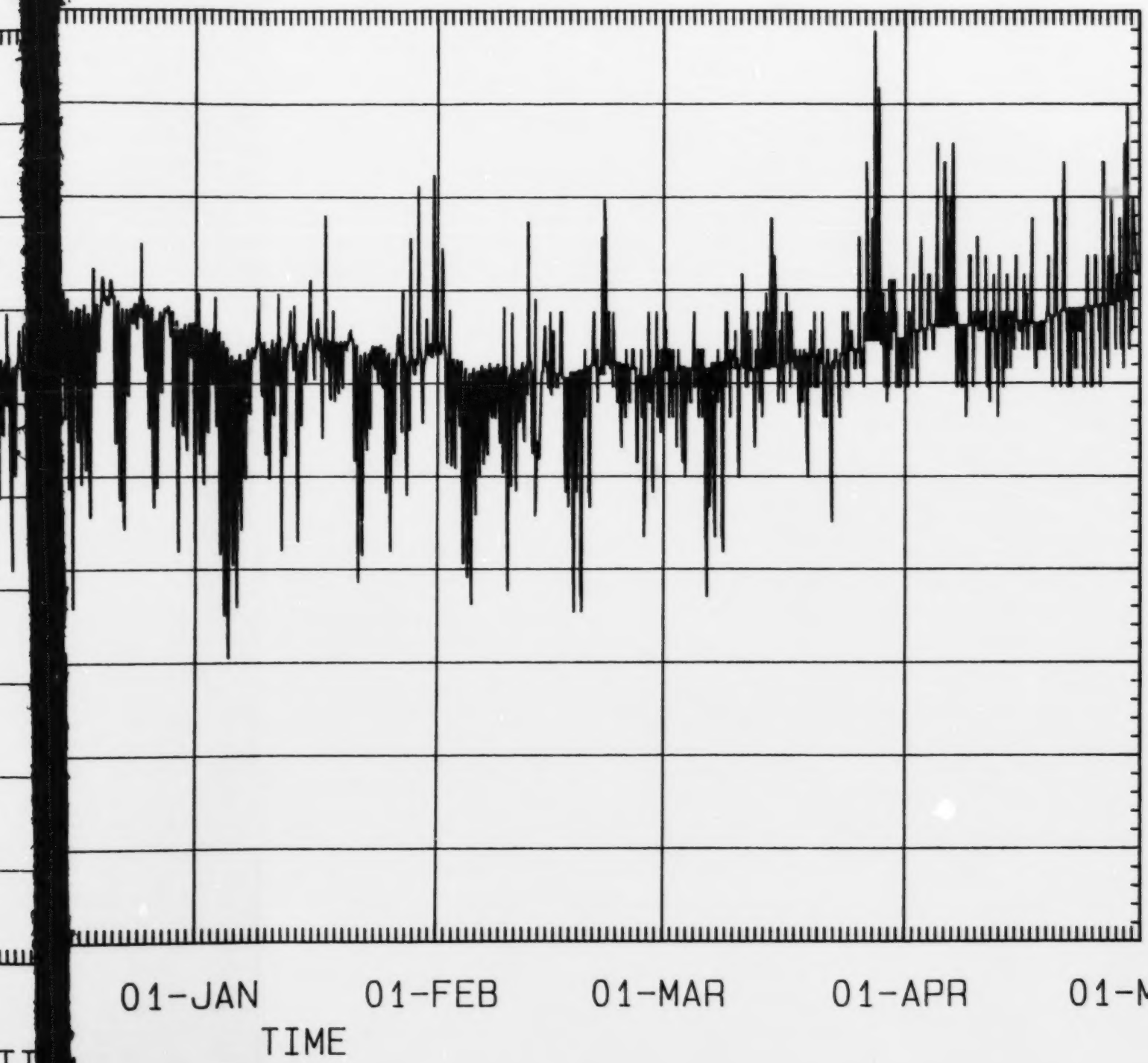
The final report will contain an executive summary in both English and French. The CANMET standard cover page must be used.

APPENDIX B

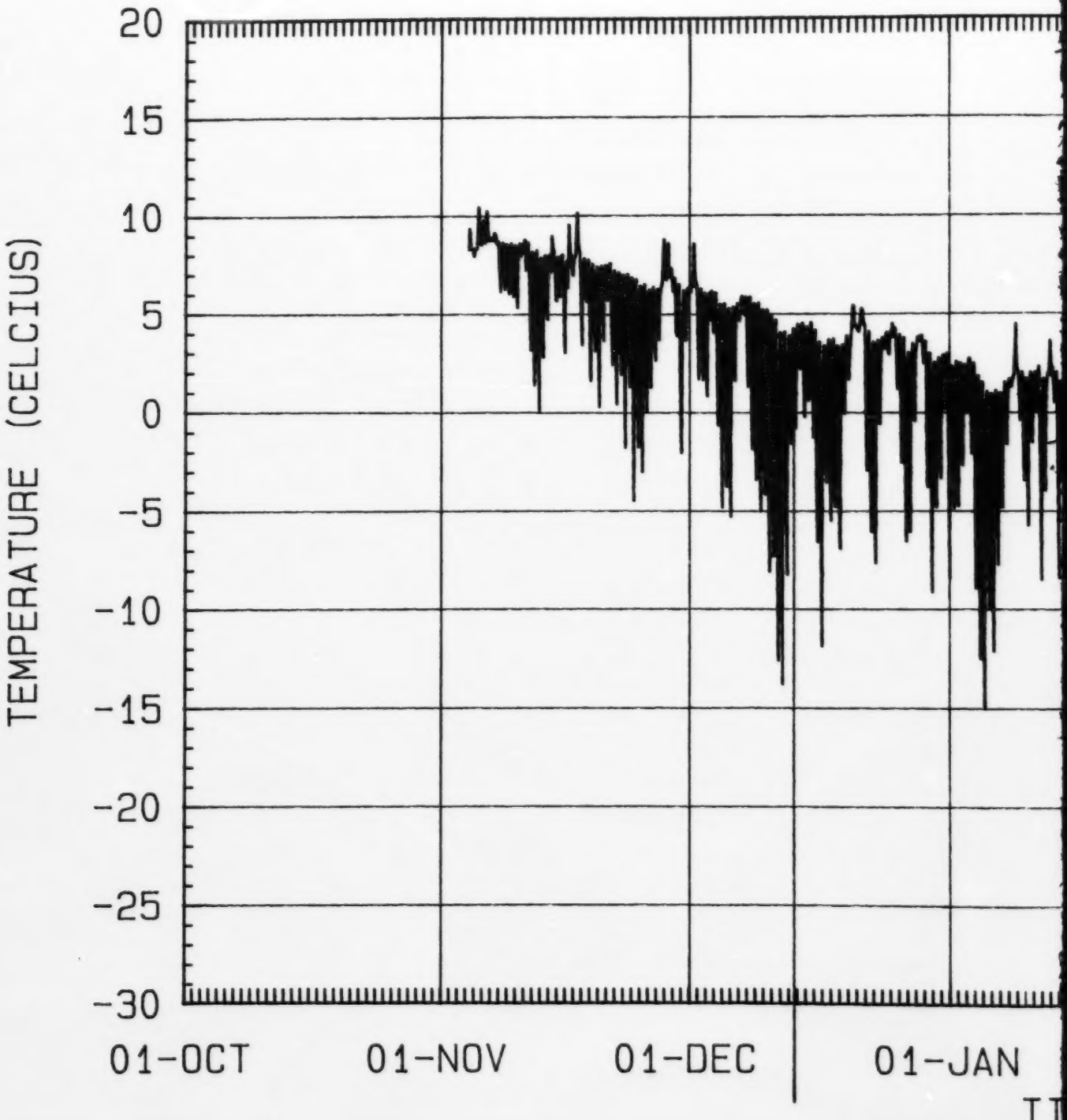
Temperature Record Winter 1988/89


TEMPERATURE RECO
915 x 305 x 305 mm
TEMPERATURE (CELCIUS)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
01-OCT
01-NOV
01-DEC
01-JAN
TI

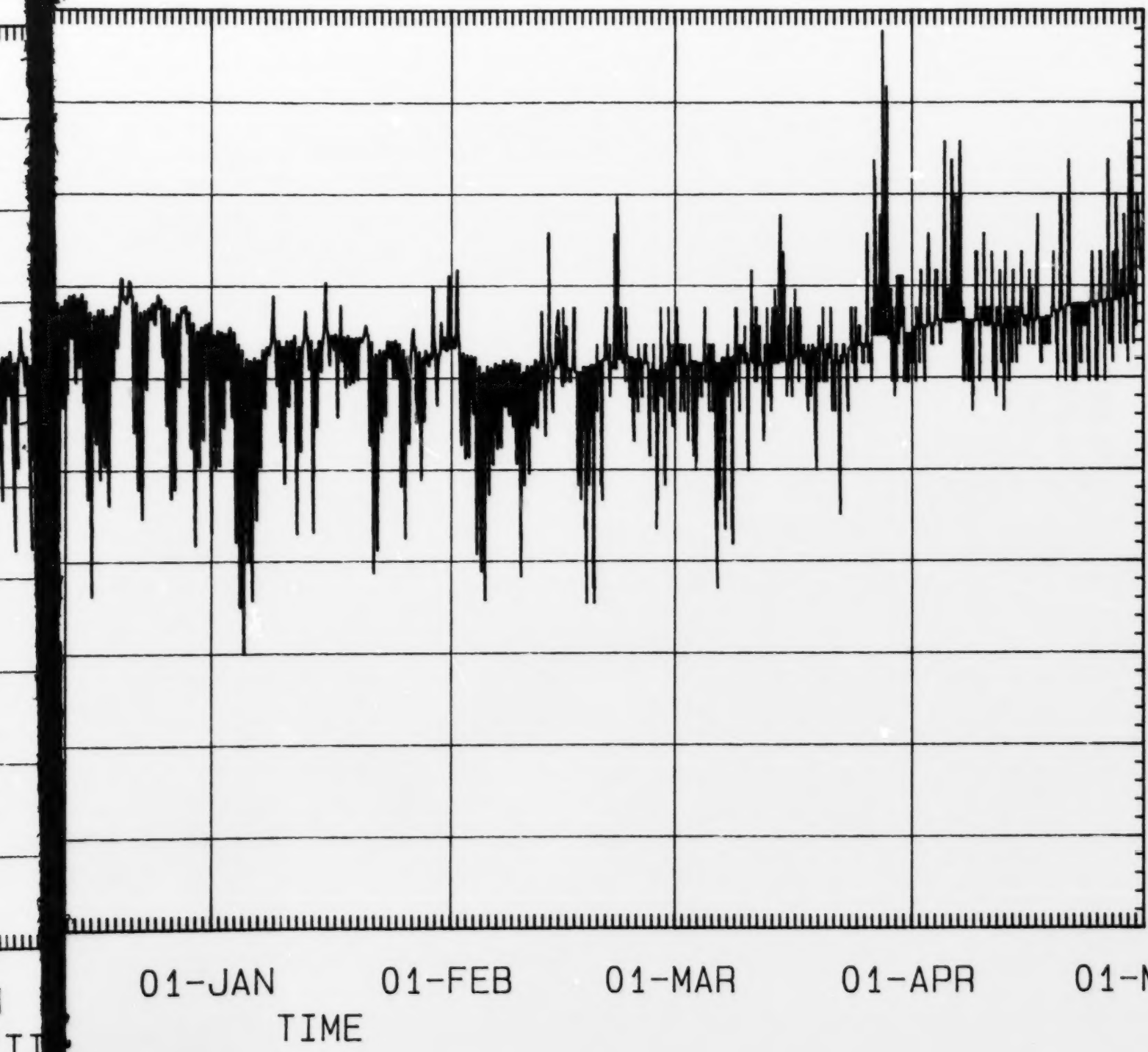
ATURE RECORD WINTER 1988/89
5 x 305 mm PRISM @ 25 mm COVER

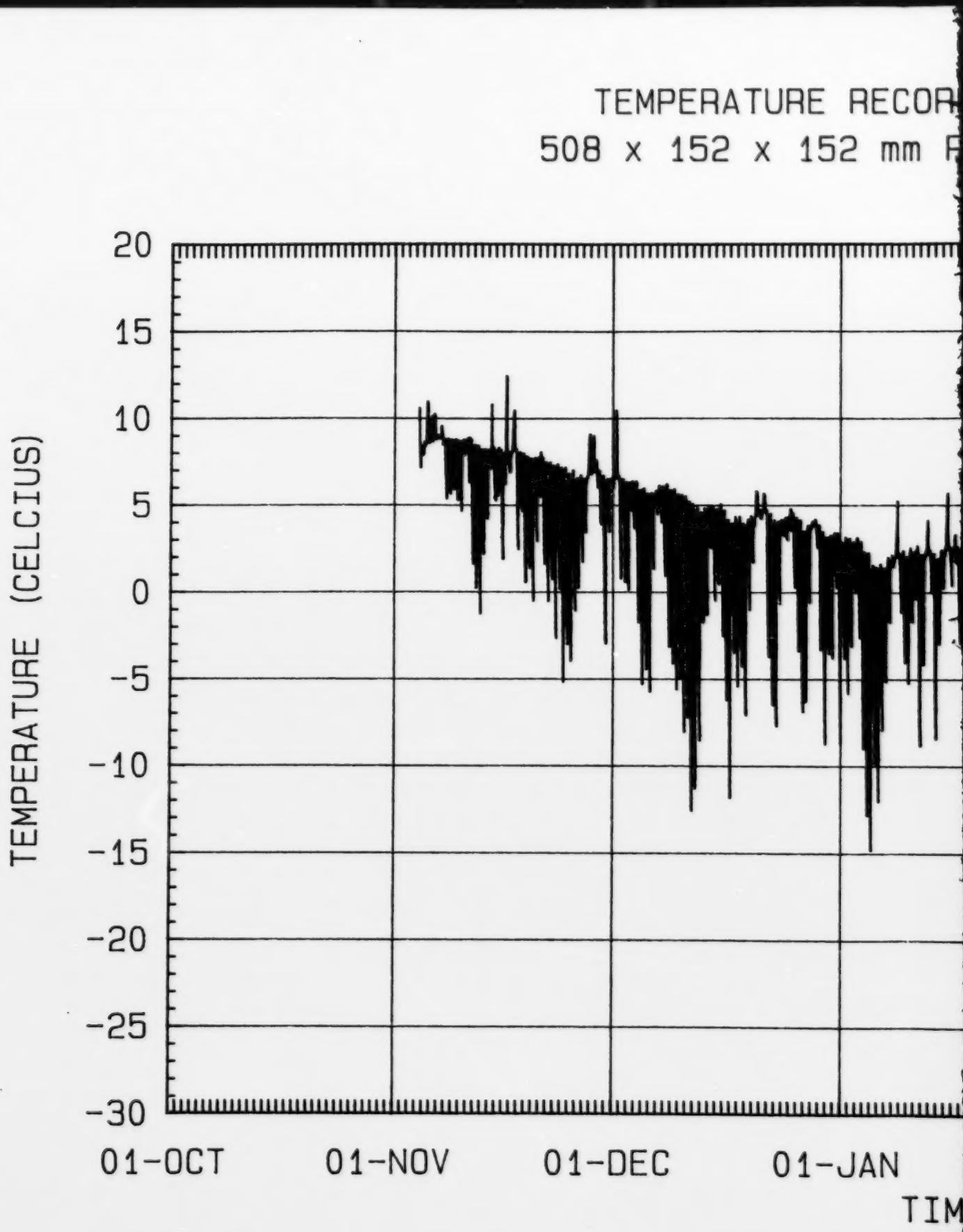


TEMPERATURE RECO
915 x 305 x 305 mm

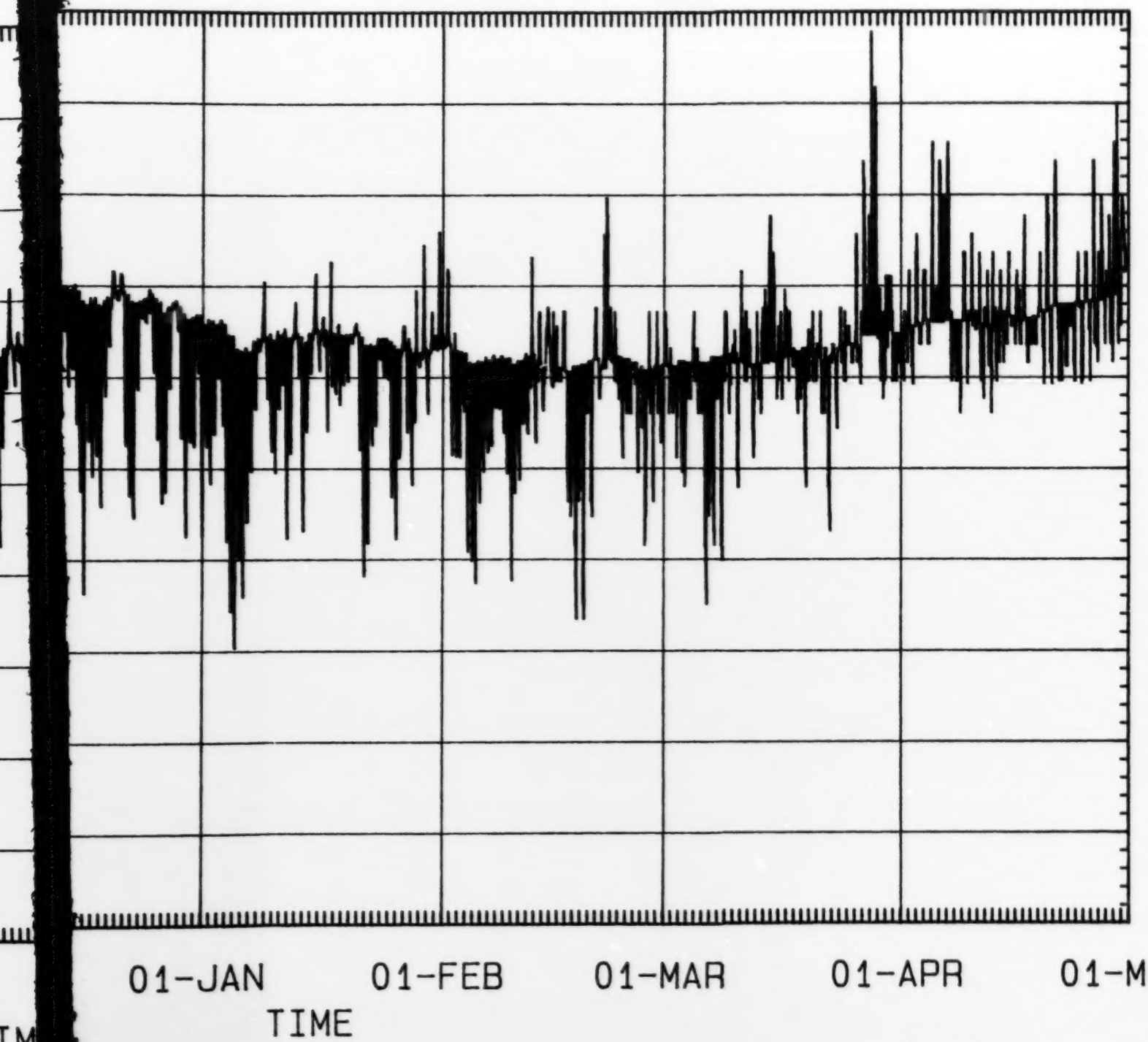


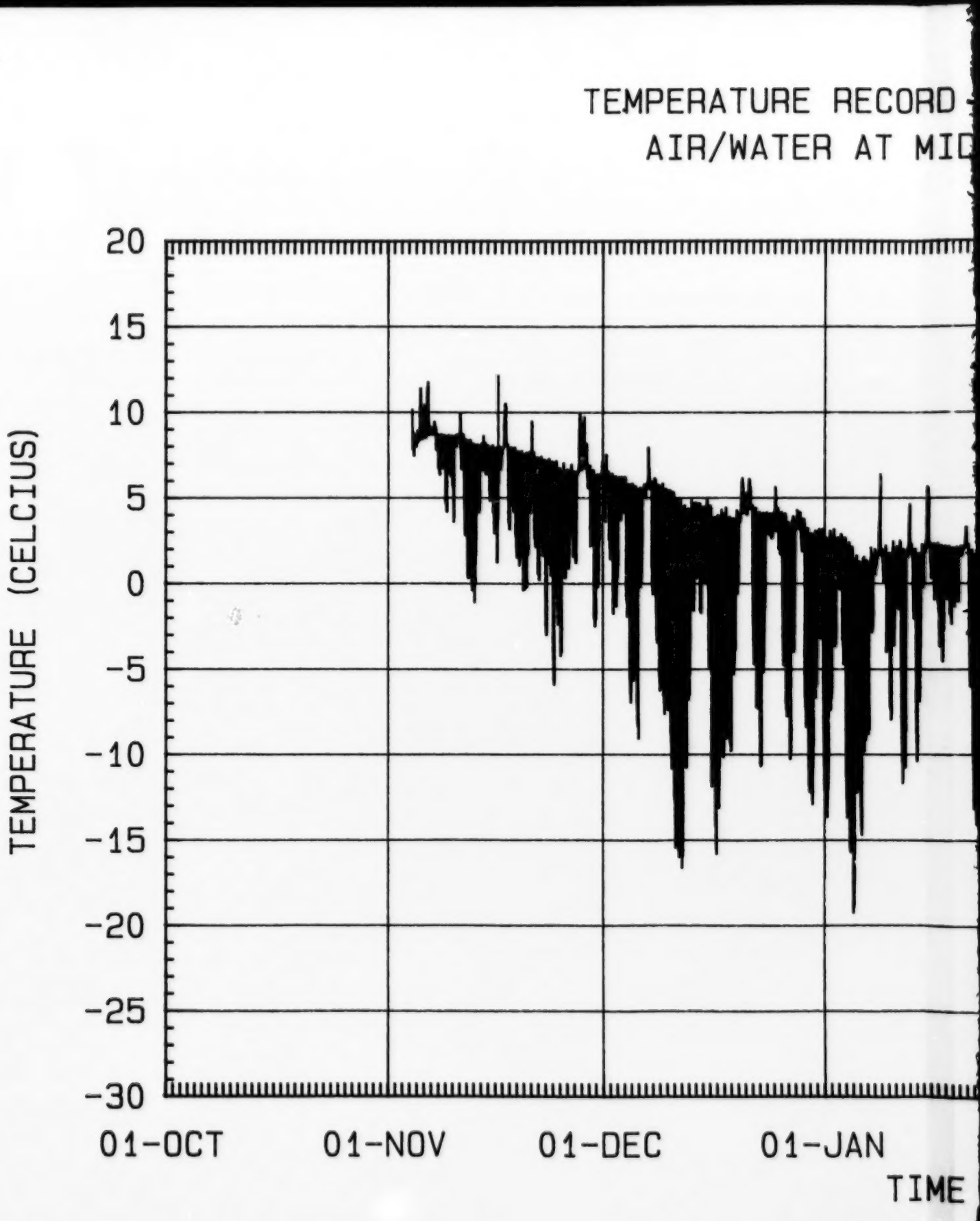
ERATURE RECORD WINTER 1988/89
5 x 305 mm PRISM @ 152 mm COVER



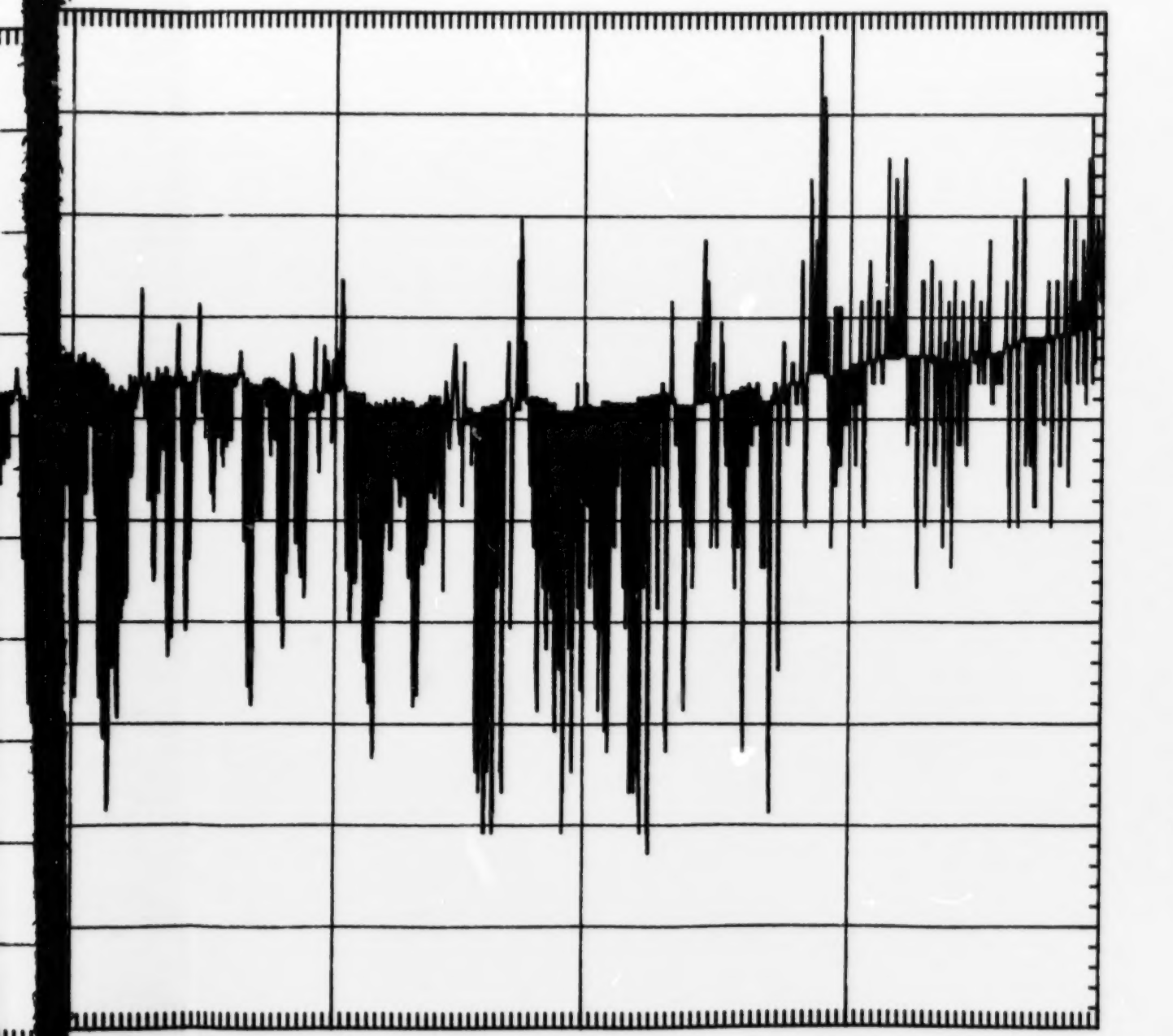

TEMPERATURE RECOR
508 x 152 x 152 mm
TEMPERATURE (CELCIUS)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
01-OCT
01-NOV
01-DEC
01-JAN
TIM

RATURE RECORD WINTER 1988/89
2 x 152 mm PRISM @ 75 mm COVER




TEMPERATURE RECORD -
AIR/WATER AT MID
TEMPERATURE (CELCIUS)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
01-OCT
01-NOV
01-DEC
01-JAN
TIME

RECORD WINTER 1988/89
R AT MID TIDE LEVEL



JAN 01-FEB 01-MAR 01-APR 01-MAY
TIME

TABLE I - Mix proportions - Phase I

Mix	Cement Type and Batch no.		W : (C+R) Ratio	Batch Quantities (kg/m^3) Water	Cement	Slag	Fly Ash	Silica Fume	F.A.	C.A.	A.E.A (ml/m^3)	Super Plasticizer (ml/m^3)
A	Type 10	1	0.4	158	396	0	0	0	590	1196	360	0
		2		160	292	97	0	0	576	1176	580	0
		3		178	318	97	0	0	553	1138	480	0
		4		181	319	106	0	0	546	1132	440	0
		5		176	443	0	0	0	558	1146	430	0
		6		176	243	199	0	0	556	1141	870	0
		7		175	243	199	0	0	554	1138	860	0
		8		176	243	199	0	0	556	1140	870	0
		9		177	445	0	0	0	558	1147	370	0
		10		176	154	287	0	0	553	1137	1130	0
		11		179	155	290	0	0	536	1102	1120	0
		12		180	156	286	0	0	538	1106	1120	0
	Type 50	13		157	392	0	0	0	600	1196	490	0
		14		158	395	0	0	0	604	1203	500	0
	Type 10	15		179	446	0	0	0	560	1152	390	0
B	Type 10	1	0.5	161	329	0	0	0	641	1168	280	0
		2		161	244	82	0	0	638	1162	380	0
		3		161	247	82	0	0	644	1173	340	0
		4		151	231	77	0	0	651	1210	320	0
		5		161	320	0	0	0	668	1224	260	0
		6		166	183	150	0	0	629	1179	450	0
		7		166	183	150	0	0	629	1178	450	0
		8		167	183	150	0	0	630	1179	460	0
		9		167	335	0	0	0	656	1184	350	0
		10		166	116	215	0	0	634	1173	590	0
		11		167	117	217	0	0	640	1165	540	0
		12		168	118	219	0	0	645	1192	540	0
	Type 50	13		157	314	0	0	0	659	1203	350	0
		14		157	313	0	0	0	656	1198	350	0
	Type 10	15		166	331	0	0	0	648	1171	370	0

TABLE I (Cont'd) - Mix proportions - Phase I

Mix	Cement Type and Batch no.		W : (C+R) Ratio	Batch Quantities (kg/m^3) Water	Cement	Slag	Fly Ash	Silica Fume	F.A.	C.A.	A.E.A (ml/m^3)	Super Plasticizer (ml/m^3)
C	Type 10	1	0.6	170	282	0	0	0	688	1222	270	0
		2		167	209	70	0	0	674	1209	320	0
		3		168	209	70	0	0	676	1210	300	0
		4		159	199	66	0	0	643	1290	300	0
		5		160	276	0	0	0	650	1248	260	0
		6		160	147	120	0	0	650	1249	390	0
		7		158	145	119	0	0	641	1231	440	0
		8		158	145	119	0	0	642	1232	410	0
		9		160	266	0	0	0	647	1243	260	0
		10		160	94	174	0	0	638	1250	380	0
		11		160	93	173	0	0	636	1246	380	0
		12		161	94	175	0	0	643	1260	390	0
	Type 50	13		163	272	0	0	0	656	1270	260	0
		14		163	272	0	0	0	663	1274	260	0
	Type 10	15		161	268	0	0	0	652	1253	260	0
SP	Type 10	1	0.5	167	334	0	0	0	654	1182	280	0
		2		166	332	0	0	0	649	1172	280	4720
		3		174	348	0	0	0	682	1232	0	6578
		4		174	349	0	0	0	683	1233	0	0
		5		165	335	0	0	0	647	1169	280	9730*
		6		172	345	0	0	0	675	1219	0	16554*

* Melamine-based superplasticizer was used

TABLE I (Cont'd) - Mix proportions - Phase II

Mix	Cement Type and Batch no.		W : (C+R) Ratio	Batch Quantities (kg/m³) Water	Cement	Slag	Fly Ash	Silica Fume	F.A.	C.A.	A.E.A (ml/m³)	Super Plasticizer (ml/m³)
D	Type 10	1	0.4	158	395	0	0	0	611	1256	390	0
		2		150	281	0	94	0	580	1192	960	0
		3		150	281	0	94	0	580	1192	960	0
		4		149	297	0	93	0	576	1184	950	0
		5		164	411	0	0	0	586	1198	370	0
		6		160	161	161	80	0	563	1152	1290	0
		7		160	161	161	80	0	564	1152	1290	0
		8		161	162	162	81	0	568	1162	1460	0
		9		164	411	0	0	0	582	1198	420	0
		10		165	83	247	82	0	564	1161	2130	0
		11		168	84	252	84	0	554	1138	1910	0
		12		168	84	252	84	0	554	1140	2070	0
	Type 50	13		153	384	0	0	0	551	1245	310	0
		14		151	379	0	0	0	542	1288	280	0
	Type 10	15		165	412	0	0	0	586	1191	300	0
	Type 20	16		148	370	0	0	0	530	1319	270	0
		17		141	355	0	0	0	510	1385	260	0
E	Type 10	1	0.5	160	320	0	0	0	664	1208	160	0
		2		160	240	0	80	0	662	1211	590	0
		3		154	231	0	77	0	637	1213	640	0
		4		151	227	0	76	0	628	1255	570	0
		5		149	298	0	0	0	657	1260	150	0
		6		160	128	128	64	0	686	1163	640	0
		7		152	122	122	61	0	652	1185	610	0
		8		154	123	123	62	0	662	1202	580	0
		9		148	297	0	0	0	656	1257	180	0
		10		143	57	171	58	0	611	1246	770	0
		11		147	59	176	59	0	628	1241	680	0
		12		148	59	177	59	0	631	1247	680	0
	Type 50	13		152	304	0	0	0	657	1258	290	0
		14		138	275	0	0	0	666	1274	240	0
	Type 10	15		147	293	0	0	0	646	1208	190	0
	Type 20	16		149	297	0	0	0	629	1233	320	0
		17		133	264	0	0	0	695	1245	260	0

TABLE I (Cont'd) - Mix proportions - Phase II

Mix	Cement Type and Batch no.		W : (C+R) Ratio	Batch Quantities (kg/m^3) Water	Cement	Slag	Fly Ash	Silica Fume	F.A.	C.A.	A.E.A (ml/m^3)	Super Plasticizer (ml/m^3)
F	Type 10	1	0.6	148	246	0	0	0	724	1247	140	0
		2		145	182	0	61	0	713	1229	440	0
		3		139	174	0	58	0	743	1179	490	0
		4		141	175	0	59	0	748	1187	460	0
		5		139	233	0	0	0	744	1179	210	0
		6		146	97	97	49	0	745	1166	540	0
		7		145	98	98	49	0	666	1239	490	0
		8		142	96	96	48	0	727	1215	480	0
		9		137	226	0	0	0	767	1147	190	0
		10		138	46	137	46	0	775	1160	540	0
		11		136	46	136	45	0	770	1152	500	0
		12		140	46	139	46	0	759	1181	510	0
	Type 50	13		135	225	0	0	0	745	1230	170	0
		14		135	224	0	0	0	743	1228	170	0
	Type 10	15		143	237	0	0	0	758	1202	150	0
	Type 20	16		126	209	0	0	0	729	1203	200	0
		17		129	216	0	0	0	721	1242	170	0

TABLE I (Cont'd) - Mix proportions - Phase III

Mix	Cement Type and Batch no.		Nominal Cement (kg/m^3)	Batch Quantities (kg/m^3) Water	Cement	Slag	Fly Ash	Silica Fume	F.A.	C.A.	A.E.A (ml/m^3)	Super Plasticizer (ml/m^3)
G	Type 10	1	237	212	240	0	0	0	866	583	70	0
		2		217	241	0	0	0	873	586	71	0
		3		215	183	61	0	0	869	589	78	0
		4		219	184	62	0	0	870	589	75	0
		5		214	183	61	0	0	865	586	78	0
		6		210	241	0	0	0	871	585	71	0
		7		210	135	111	0	0	877	596	92	0
		8		207	133	109	0	0	864	587	94	0
		9		210	133	109	0	0	862	585	94	0
		10		204	239	0	0	0	864	581	78	0
		11		207	84	157	0	0	856	583	99	0
		12		209	85	158	0	0	868	592	94	0
		13		206	85	158	0	0	863	588	99	0
	Type 50	14		202	241	0	0	0	871	586	125	0
		15		196	243	0	0	0	879	591	135	0
H	Type 10	1	356	215	356	0	0	0	777	589	102	0
		2		216	355	0	0	0	775	589	111	0
		3		222	268	90	0	0	764	590	121	0
		4		226	263	88	0	0	751	580	119	0
		5		220	266	88	0	0	758	584	120	0
		6		221	353	0	0	0	771	585	113	0
		7		220	198	162	0	0	750	587	155	0
		8		221	199	163	0	0	753	589	140	0
		9		220	199	163	0	0	754	590	133	0
		10		217	355	0	0	0	774	588	113	0
		11		209	129	239	0	0	747	592	191	0
		12		215	128	238	0	0	761	598	167	0
		13		226	122	227	0	0	768	594	159	0
	Type 50	14		200	352	0	0	0	759	595	194	0
		15		202	355	0	0	0	765	600	167	0

TABLE I (Cont'd) - Mix proportions - Phase III

Mix	Cement Type and Batch no.		Nominal Cement (kg/m^3)	Batch Quantities (kg/m^3)							A.E.A	Super Plasticizer
				Water	Cement	Slag	Fly Ash	Silica Fume	F.A.	C.A.	(ml/m^3)	(ml/m^3)
I	Type 10	1	475	222	473	0	0	0	661	571	151	0
		2		227	475	0	0	0	664	573	154	0
		3		224	360	129	0	0	653	574	195	0
		4		225	363	121	0	0	659	578	178	0
		5		225	357	119	0	0	667	580	187	0
		6		247	474	0	0	0	646	568	198	0
		7		247	261	214	0	0	616	565	231	0
		8		243	261	214	0	0	616	565	252	0
		9		239	271	221	0	0	638	575	279	0
		10		221	469	0	0	0	655	567	173	0
		11		214	166	307	0	0	628	565	266	0
		12		220	169	314	0	0	641	577	272	0
		13		217	167	310	0	0	635	571	269	0
	Type 50	14		211	465	0	0	0	648	576	351	0
		15		212	465	0	0	0	650	577	352	0

TABLE I (Cont'd) - Mix proportions - Phase IV

Mix	Cement Type and Batch no.		W : (C+R) Ratio	Batch Quantities (kg/m^3) Water	Cement	Slag	Fly Ash	Silica Fume	F.A.	C.A.	A.E.A (ml/m^3)	Super Plasticizer (ml/m^3)
J	Type 10	1	0.4	178	440	0	0	0	586	1128	415	0
		2		178	440	0	0	0	586	1128	376	0
		3		179	442	0	0	0	589	1134	345	0
		4		170	318	0	106	0	529	1140	832	0
		5		163	305	0	101	0	507	1239	683	0
		6		170	319	0	106	0	530	1239	633	0
	Type 50	7		171	429	0	0	0	605	1214	367	0
		8		166	414	0	0	0	627	1171	427	0
K	Type 10	1	0.5	174	348	0	0	0	639	1211	306	0
		2		173	346	0	0	0	635	1204	333	0
		3		173	345	0	0	0	634	1201	325	0
		4		163	244	0	81	0	625	1249	519	0
		5		160	240	0	80	0	632	1244	590	0
		6		160	241	0	80	0	622	1236	580	0
	Type 50	7		156	311	0	0	0	688	1226	337	0
		8		150	300	0	0	0	695	1246	324	0
L	Type 10	1	0.6	159	263	0	0	0	730	1217	229	0
		2		160	260	0	0	0	737	1201	226	0
		3		158	262	0	0	0	731	1210	228	0
		4		148	183	0	61	0	742	1225	425	0
		5		149	184	0	61	0	760	1226	426	0
		6		148	186	0	62	0	751	1239	430	0
	Type 50	7		147	244	0	0	0	777	1241	255	0
		8		146	242	0	0	0	769	1229	286	0

TABLE I (Cont'd) - Mix proportions - Phase V

Mix	Cement Type and Batch no.		W : (C+R) Ratio	Batch Quantities (kg/m³) Water	Cement	Slag	Fly Ash	Silica Fume	F.A.	C.A.	A.E.A (ml/m³)	Super Plasticizer (ml/m³)
M	Type 10	1	0.4	174	435	0	0	0	581	1120	435	0
		2		177	443	0	0	0	590	1137	407	0
		3		179	89	357	0	0	571	1146	1193	849
		4		177	88	354	0	0	567	1137	1906	1183
N	Type 10	1	0.5	164	329	0	0	0	729	1147	143	0
		2		163	327	0	0	0	726	1143	177	0
		3		162	65	259	0	0	710	1130	456	333
		4		160	64	256	0	0	701	1115	389	343
O	Type 10	1	0.6	154	260	0	0	0	751	1148	143	0
		2		155	257	0	0	0	754	1194	177	0
		3		151	260	202	0	0	724	1159	456	0
		4		153	259	204	0	0	733	1174	389	0
P	Type 10	1	0.6	157	260	0	0	0	802	1101	203	0
		2		155	257	0	0	26	767	1087	368	957
		3		158	262	0	0	39	764	1105	468	2248
		4		157	259	0	0	52	742	1095	776	2894
Q	Type 10	1	0.6	146	243	0	0	0	804	1125	196	0
		2		146	218	0	0	24	799	1125	417	1572
		3		146	206	0	0	36	790	1125	540	2525
		4		147	196	0	0	49	791	1135	672	2674
R	Type 10	1	0.6	167	278	0	0	0	838	1129	0	0
		2		171	256	0	0	28	848	1159	0	3250
		3		170	240	0	0	43	837	1149	0	4236
		4		170	226	0	0	56	834	1149	0	4409

TABLE I (Cont'd) - Mix proportions - Phase VI

Mix	Cement Type and Batch no.		Nominal Cement (kg/m^3)	Batch Quantities (kg/m^3)							A.E.A (ml/m^3)	Super Plasticizer (ml/m^3)
				Water	Cement	Fiber	Fly Ash	Silica Fume	F.A.	C.A.		
S	Type 10	1	632	238	492	-	84	39	527	561	2410	5360
		2		243	502	-	85	40	493	573	1684	2882
		5		244	632	-	-	-	508	577	652	2740
		6		253	501	50.2	85	40	403	584	958	5196
		7		252	505	50.6	86	40	407	589	912	5990
T	Type 10	1	509	227	408	-	70	33	587	606	594	2716
		2		228	408	-	69	32	582	601	657	2712
		5		230	509	-	-	-	612	600	361	2462
		6		245	391	48.8	66	31	570	598	518	3710
		7		237	394	48.2	67	32	563	590	630	4770
U	Type 10	1	375	225	303	-	51	24	692	596	448	3792
		2		236	308	-	52	25	704	616	232	2533
		5		235	375	-	-	-	799	590	210	2146
		6		228	307	51.2	52	25	658	591	297	3165
		7		221	303	50.7	52	24	668	600	292	3736

TABLE I (Cont'd) - Mix proportions - Phase VII

Mix	Cement Type and Batch no.		Nominal Cement (kg/m^3)	Batch Quantities (kg/m^3)								
				Water	Cement	Fiber	Fly Ash	Silica Fume	F.A.	C.A.	A.E.A (ml/m^3)	Super Plasticizer (ml/m^3)
V	Type 10	1	500	140	500	-	-	30	700	550	800	4000
		2		140	500	-	-	30	700	550	800	4000
		3		140	500	-	-	30	700	550	800	4000
W		1	400	145	400	-	-	30	660	635	750	2500
		2		145	400	-	-	30	660	635	750	2500
		3		145	400	-	-	30	660	635	750	2500

TABLE I (Cont'd) - Mix proportions - Phase VIII

Mix	Cement Type and Batch no.		W : (C+R*) Ratio	Batch Quantities (kg/m³) Water	Cement	Slag	Fly Ash	Silica Fume	F.A.	C.A.
X	Type I	1	0.38	132	347		0		864	1039
		2	0.39	134	345		0		860	1034
		3	0.31	109	157		199		827	1152
		4	0.31	107	157		199		827	1153
Y	Type I	1	0.46	139	306		0		835	1074
		2	0.46	139	304		0		830	1068
		3	0.35	123	154		195		768	1129
		4	0.35	124	156		197		775	1140

* R = fly ash by weight

TABLE I (Cont'd) - Mix proportions - Phase IX

Mix	Cement Type and Batch no.		W : (C+R*) Ratio	Batch Quantities (kg/m³) Water	Cement	Slag	Fly Ash	Silica Fume	F.A.	C.A.
Z	Type I	1	0.50	164	328	-	-	-	789	1048
		2		170	339	-	-	-	781	1048
		3		155	233	-	78	-	781	1053
		4		152	228	-	76	-	764	1030
		5		164	295	-	-	33	772	1030
		6		163	291	-	-	33	762	1017
		7		159	159	159	-	-	758	1051
		8		160	160	160	-	-	763	1057

* R = slag + fly ash + silica fume by weight

NOTE: Specimens Z01 to Z08 contain steel reinforcing.

TABLE I (Cont'd) - Mix proportions - Phase IX

Mix	Silica Fume	Cement	Water	F.A.	C.A.	AEA ml/m^3
AA-1	29.8	410.5	177.3	671.7	617.4	274
AA-2	30.3	417.2	176.3	682.8	627.6	342
AA-3	30.2	415.7	176.6	680.2	625.2	214
AA-4	30.1	414.3	178.7	677.9	623.1	339
AB-1	31.4	435.5	159.9	773.4	509.2	367
AB-2	31.3	433.2	165.4	769.4	506.6	331
AB-3	31.4	434.6	156.3	771.8	508.2	341
AB-4	31.4	434.3	163.7	771.3	507.8	426
AC-1	29.6	410.7	157.9	660.4	643.7	362
AC-2	29.9	410.7	157.9	660.4	643.7	362
AC-3	29.7	410.8	152.4	657.5	641.9	367
AC-4	29.9	414.4	158.1	663.3	647.6	332

Note: F.A. and C.A. at SSD. Moisture content as SSD
Based on Oven Dry Weight = 100%

TABLE II

Ultrasonic Pulse Transit Time Readings (microseconds)

PRISM NO.	READING
A01	203.6
A02	215.3
A03	213.4
A05	209.4
A06	216.8
A07	218.5
A09	209.5
A10	221.4
A11	224.4
A13	208.7
B01	211.4
B02	210.8
B03	211.1
B05	213.4
B06	215.4
B07	214.1
B09	212.7
B10	218.8
B11	218.6
B13	207.6
C01	212.2
C02	213.3
C03	212.9
C05	211.4
C06	212.5
C07	213.6
C09	212.5
C10	217.4
C11	219.8
C13	211.6
SP1	210.8
SP2	215.7
SP3	-
SP4	-
SP5	207.3
SP6	-

TABLE II (cont'd)

Ultrasonic Pulse Transit Time Readings (microseconds)

PRISM NO.	READING
D01	208.5
D02	211.3
D03	210.6
D05	204.4
D06	219.9
D07	220.6
D09	204.0
D10	238.8
D11	235.4
D13	210.0
D16	204.8
E01	209.4
E02	209.8
E03	218.8
E05	210.5
E06	226.8
E07	223.4
E09	208.6
E10	236.2
E11	235.7
E13	207.5
E16	210.4
F01	215.6
F02	218.8
F03	219.5
F05	216.0
F06	247.0
F07	246.8
F09	219.7
F10	246.0
F11	256.8
F13	217.6
F16	222.0

TABLE II (cont'd)

Ultrasonic Pulse Transit Time Readings (microseconds)

PRISM NO.	READING
G01	248.4
G02	260.4
G03	240.2
G06	240.6
G07	232.6
G08	238.4
G10	248.6
G11	299.2
G12	257.8
G14	263.6
H01	228.6
H03	225.4
H04	229.2
H06	228.8
H07	225.3
H08	226.6
H10	230.4
H11	225.8
H12	225.7
H14	229.1
I01	224.3
I03	222.4
I04	219.6
I06	225.1
I07	221.9
I08	224.1
I10	226.2
I11	227.4
I12	224.8
I14	224.3
J01	197.6
J02	196.3
J04	204.4
J05	199.3
J07	191.6

TABLE II (cont'd)
Ultrasonic Pulse Transit Time Readings (microseconds)

PRISM NO.	READING
K01	195.8
K02	196.8
K04	193.8
K05	199.4
K07	198.3
L01	200.5
L02	203.4
L04	200.8
L05	197.6
L07	205.8
M01	199.4
M02	196.0
M03	215.5
M04	214.1
N01	201.8
N02	194.9
N03	221.8
N04	222.3
O01	202.2
O02	202.9
O03	224.3
O04	219.0
P01	207.3
P02	208.7
P03	202.4
P04	207.6
Q01	208.6
Q02	205.3
Q03	205.6
Q04	227.6
R01	207.8
R02	203.8
R03	202.8
R04	205.7

TABLE II (cont'd)
Ultrasonic Pulse Transit Time Readings (microseconds)

PRISM NO.	READING
S01	225.4
S02	224.2
S05	221.8
S06	227.4
S07	225.4
T01	224.6
T02	226.6
T05	221.4
T06	226.4
T07	228.4
U01	228.4
U02	228.8
U05	225.8
U06	229.6
U07	229.6
V01	217.2
V02	215.5
V03	215.5
W01	224.3
W02	226.8
W03	225.3
X01	194.9
X02	192.1
X03	187.2
X04	187.6
Y01	197.6
Y02	196.6
Y03	192.6
Y04	192.9
Z01	207.7
Z02	209.3
Z03	216.5
Z04	225.4
Z05	223.4
Z06	220.2
Z07	224.9
Z08	223.3

TABLE II (cont'd)
Ultrasonic Pulse Transit Time Readings (microseconds)

PRISM NO.	1 TOP RIGHT	2 TOP LEFT	3 BOTTOM LEFT	4 BOTTOM RIGHT	5 CENTRE
AA1	225.4	227.4	226.6	227.0	229.1
AA2	226.0	225.4	228.6	226.3	229.6
AB1	228.4	230.3	231.0	229.8	232.8
AB2	232.5	232.6	234.4	231.6	234.6
AC1	227.8	228.5	226.4	226.3	227.5
AC2	229.3	229.8	228.3	229.6	229.2

TABLE III

Resonant Frequency Readings

SERIES	1st HARMONIC FREQUENCY (H_Z)
A01	1211
A02	1167
A03	1149
A05	1177
A06	1164
A07	1151
A09	1182
A10	1166
A11	1156
A13	1201
B01	1146
B02	1147
B03	1160
B05	1171
B06	1153
B07	1172
B09	1144
B10	1150
B11	1103
B13	1177
C01	1153
C02	1163
C03	1171
C05	1133
C06	1174
C07	1154
C09	1148
C10	1180
C11	1180
C13	1183
SP1	1161
SP2	1130
SP3	Damaged
SP4	Damaged
SP5	1155
SP6	Missing

TABLE III (cont'd)

Resonant Frequency Readings

SERIES	1st HARMONIC FREQUENCY (H_z)
D01	1191
D02	1131
D03	1162
D05	1209
D06	1153
D07	1141
D09	1185
D10	1082
D11	1092
D13	1159
D16	1185
E01	1185
E02	1174
E03	1140
E05	1172
E06	1130
E07	1135
E09	1185
E10	1078
E11	1079
E13	1175
E16	1144
F01	1145
F02	1152
F03	1122
F05	1131
F06	1076
F07	1083
F09	1098
F10	1011
F11	1043
F13	1134
F16	1088
G01	1007
G03	1038
G04	1039
G06	1018
G07	1074
G08	1074
G10	1016
G11	1051
G12	1048
G14	1008

TABLE III (cont'd)

Resonant Frequency Readings

SERIES	1st HARMONIC FREQUENCY (H_Z)
H01	1084
H03	1100
H04	1076
H06	1077
H07	1099
H08	1078
H10	1090
H11	1101
H12	1104
H14	1073
I01	1105
I03	1116
I04	1114
I06	1091
I07	1107
I08	1094
I10	1067
I11	1084
I12	1104
I14	1103
J01	1208
J02	1201
J04	1193
J05	1228
J07	1274
K01	1224
K02	1204
K04	1252
K05	1242
K07	1188
L01	1173
L02	1151
L04	1196
L05	1216
L07	1152
M01	1250
M02	1242
M03	1197
M04	1188

TABLE III (cont'd)

Resonant Frequency Readings

SERIES	1st HARMONIC FREQUENCY (H_Z)
N01	1191
N02	1227
N03	1198
N04	1152
O01	1196
O02	1177
O03	1150
O04	1159
P01	1162
P02	1166
P03	1210
P04	1168
Q01	1154
Q02	1196
Q03	1179
Q04	1171
R01	1019
R02	
R03	1188
R04	1221
S01	1088
S02	1090
S05	1105
S06	1081
S07	1068
T01	1082
T02	1074
T05	1129
T06	1078
T07	1068
U01	1082
U02	1082
U05	1110
U06	1075
U07	1094

TABLE III (cont'd)

Resonant Frequency Readings

SERIES	1st HARMONIC FREQUENCY (H_Z)
V01	1094
V02	1092
V03	1102
W01	1122
W02	1128
W03	1126
X01	1286
X02	1294
X03	1361
X04	1341
Y01	1263
Y02	1262
Y03	1292
Y04	1317
Z01	1191
Z02	1173
Z03	1143
Z04	1124
Z05	1144
Z06	1139
Z07	1136
Z08	1152
AA1	1089
AA2	1097
AB1	1061
AB2	1052
AC1	1074
AC2	1067

TABLE IV

Rating of Specimens

SERIES	RATING	REMARKS
A01	1	
A02	1	
A03	1	
A05	2	
A06	2	Some loss of mortar
A07	2	Some loss of mortar
A09	2	
A10	2	Some loss of mortar
A11	2	Some loss of mortar
A13	2	Some loss of mortar
B01	1	
B02	2	Some loss of mortar
B03	2	Some loss of mortar
B05	1	
B06	2	2 mm loss of mortar
B07	2	Some loss of mortar
B09	2	
B10	3	Some loss of mortar
B11	3	Large spall-holds water, damage spreading to 100 x 160 ellipse 38 mm deep
B13	1	Some loss of mortar

TABLE IV (cont'd)

Rating of Specimens

SERIES	RATING	REMARKS
C01	2	Slight end damage
C02	2	Slight end damage
C03	3	2 mm loss of mortar
C05	1	Slight end scaling
C06	2	Some end damage
C07	3	5 mm loss of mortar
C09	2	
C10	5	8 mm loss of mortar
C11	4	6 mm loss of mortar
C13	2	2 mm loss of water
SP1	2	Some loss of mortar
SP2	2	Some loss of mortar
SP3	10	0% of specimen remaining
SP4	8	60% of specimen remaining
SP5	2	Some loss of mortar
SP6	10	0% of specimen remaining
D01	2	Some loss of mortar
D02	1	Some loss of mortar
D03	2	1 mm loss of mortar
D05	2	1 mm loss of mortar
D06	3	3 mm loss of mortar
D07	4	4 mm loss of mortar
D09	1	1 mm loss of mortar
D10	6	8 mm loss of mortar
D11	6	8 mm loss of mortar
D13	1	Some loss of mortar
D16	2	Some loss of mortar
E01	2	Popout
E02	2	Some loss of mortar
E03	2	Some loss of mortar
E05	2	Some loss of mortar
E06	5	5 mm loss of mortar
E07	6	7 mm loss of mortar
E09	2	1 mm loss of mortar
E10	6	9 mm loss of mortar
E11	6	12 mm loss of mortar
E13	2	
E16	1	

TABLE IV (cont'd)

Rating of Specimens

SERIES	RATING	REMARKS
F01	1	Some loss of mortar
F02	2	Popout
F03	2	Popout
F05	2	1 mm loss of mortar
F06	7	Loss of aggregates
F07	6	Loss of aggregates
F09	2	Some loss of mortar
F10	7	Loss of aggregates
F11	7	Loss of aggregates
F13	2	Some loss of mortar
F16	1	Some loss of mortar
G01	3	Loss of 2 mm of mortar popout
G03	3	Loss of 3 mm of mortar popout
G04	3	Loss of 4 mm of mortar
G06	2	Loss of 2 mm of mortar
G07	3	Loss of 3 mm of mortar
G08	3	Loss of 4 mm of mortar popout - 2 of
G10	3	Loss of 3 mm of mortar
G11	6	Loss of 6 mm of mortar popout - 2 of
G12	5	Loss of 5 mm of mortar popout - 4 of
G14	4	Loss of 2 mm of mortar
H01	1	Loss of 1 mm of mortar
H03	2	Loss of 2 mm of mortar
H04	2	Loss of 3 mm of mortar
H06	1	Loss of 1 mm of mortar
H07	2	Loss of 2 mm of mortar popout
H08	2	Loss of 2 mm of mortar popout
H10	1	Loss of 0 mm of mortar
H11	2	Loss of 2 mm of mortar popout
H12	2	Loss of 2 mm of mortar popout
H14	1	Loss of 1 mm of mortar popout
I01	1	Loss of 1 mm of mortar
I03	1	popout
I04	1	Loss of 1 mm of mortar
I06	1	Loss of 1 mm of mortar
I07	1	Loss of 2 mm of mortar popout
I08	2	Loss of 2 mm of mortar
I10	1	Loss of 1 mm of mortar
I11	1	Loss of 2 mm of mortar
I12	2	Loss of 1 mm of mortar popout - 3 of
I14	1	Loss of 1 mm of mortar

TABLE IV (cont'd)

Rating of Specimens

SERIES	RATING	REMARKS
J01	1	
J02	1	
J04	1	Some loss of mortar
J05	2	
J07	1	
K01	1	
K02	1	
K04	2	Loss of 5 mm of mortar
K05	2	Loss of 5 mm of mortar
K07	1	Some loss of mortar
L01	1	
L02	1	Some loss of mortar
L04	4	Loss of 8 mm of mortar
L05	3	Loss of 7 mm of mortar
L07	1	10 aggregates exposed
M01	1	
M02	0	
M03	1	
M04	0	
N01	0	
N02	0	
N03	1	Some loss of mortar
N04	1	Some loss of mortar
O01	1	Some loss of mortar
O02	1	Some loss of mortar
O03	3	2 mm loss of mortar, aggregate exposed on shore end
O04	3	1 mm loss of mortar, aggregate exposed on shore end
P01	2	Some loss of mortar
P02	2	Some loss of mortar
P03	4	Some loss of mortar
P04	4	Some loss of mortar
Q01	2	1 mm loss of mortar
Q02	2	Some loss of mortar
Q03	3	1 mm loss of mortar
Q04	4	3 mm loss of mortar
R01	6	Some loss of mortar
R02	7	Some loss of mortar
R03	6	Some loss of mortar
R04	6	4 mm loss of mortar

TABLE IV (cont'd)

Rating of Specimens

SERIES	RATING	REMARKS
S01	0	
S02	0	
S05	0	
S06	0	
S07	2	
T01	0	
T02	0	
T05	0	
T06	1	
T07	1	
U01	1	
U02	1	
U05	0	
U06	1	
U07	1	
V01	0	500-1
V02	0	500-2
V03	0	500-3
W01	0	400-1
W02	0	400-2
W03	0	400-3
X01	0	
X02	0	
X03	0	
X04	0	
Y01	0	
Y02	0	
Y03	1	
Y04	1	
Z01	0	
Z02	0	
Z03	0	
Z04	0	
Z05	0	
Z06	0	
Z07	0	
Z08	1	
AA1	0	
AA2	0	
AB1	0	
AB2	0	
AC1	0	
AC2	0	

TABLE V

Freeze-Thaw Cycles of Concrete at Treat Island 1988/1989

FREEZE PT.	PRISM 305x305x915 mm COVER- (25 mm)	PRISM 305x305x915 mm COVER- (152 mm)	PRISM 152x152x510 mm COVER- (75 mm)	AIR/WATER
0.0	155	150	171	214
-1.0	129	129	145	188
-2.0	102	97	123	156
-2.2	95	95	106	148
-3.0	84	84	91	121
-4.0	69	68	73	104
-5.0	55	53	61	92
-6.0	52	43	49	81
-7.0	33	35	39	73
-8.0	27	27	34	62
-9.0	19	21	22	56
-10.0	14	15	16	47
-11.0	9	11	14	41
-12.0	6	8	7	29
-13.0	5	7	4	23
-14.0	3	4	4	18
-15.0	0	1	4	15